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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL MEMORANDUM

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PARTICULATE MATERIALS AND PROCESSES A NAVY OVERVIEW

by

Dr. William E. Frazier

8 May 1997

Aerospace Materials Division
Air Vehicle and Crew Systems Technology Department
Naval Air Warfare Center Aircraft Division
Patuxent River, Maryland

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DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
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ABSTRACT

The Navy is using, or is considering to use, particulate materials in a variety of applications throughout the air, surface, and submarine fleets. The applications range from aircraft engine turbine disks, which are needed to meet performance requirements, to direct powder sprayed parts, which greatly decrease manufacturing costs. This technical memorandum will discuss many of the applications and the reasoning behind their selection, as well as the direction of future technology.

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FIGURES

INTRODUCTION

A Navy overview of any class of materials must begin with a discussion of the unique naval operating environment. Anyone who has seen "Victory at Sea" knows of ships crashing through waves and becoming covered with salt spray. The sea has not changed since WWII, and though modern ships are bigger, they still become covered with sea water as shown in figure 1. Now, however, the ships are packed with sophisticated weapon systems, such as aircraft and armament systems that are much more susceptible to corrosion than the ships themselves. In addition, salt spray is only part of the naval environment. Other aspects include hot, humid conditions on tropical seas where water condenses on all surfaces and activates any salt deposits, high velocity sea water around propellers and shafts on ships; high pressure, high velocity sea water in the pipes, tanks, and pumps of submarines, and airborne salt particles at low altitudes over the sea and airbases near the sea.

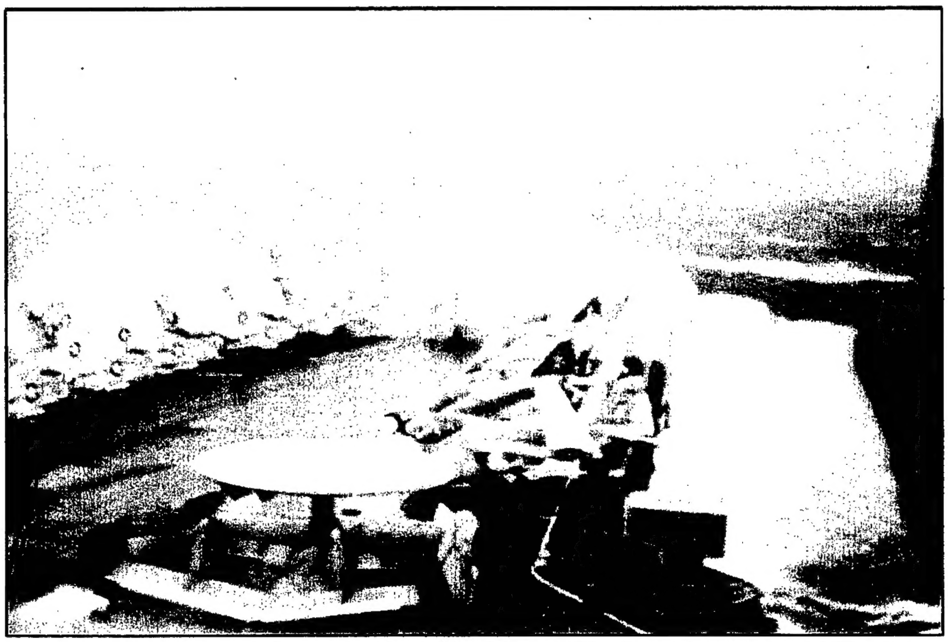


Figure 1
THE NAVY OPERATING ENVIRONMENT

Particulate material products are being used or investigated for future use in a large number of critical Navy systems from aircraft engines to shipboard waste incinerators. In many cases, particulate processing is the only way to make the required high performance alloys. It is also a lower cost alternative to more conventional processing methods, and in the Navy, as in most businesses, saving money whenever possible is a vital concern.

This technical memorandum will first discuss the current and near-term usage of particulate materials in naval systems, and then look at current research programs. Finally, there will be a discussion of advanced research.

CURRENT AND ANTICIPATED USAGE IN NAVAL SYSTEMS

AIRCRAFT SYSTEMS

AIRFRAMES

There is no significant current usage of particulate materials in airframes. Investigations have been made into powder processing of titanium alloy structural components, but a cost advantage could not be shown. The most likely near-term applications are discontinuously reinforced aluminum (DRA) alloys and aluminum beryllium (AlBe). Both have lower densities then conventional aluminum alloys and retain their critical properties at higher temperatures. DRA alloys have higher strength and better fatigue resistance as shown in figure 2, while AlBe alloys have a much higher modulus than other alloy systems as shown in figure 3. AlBe alloy rudders for the F-15 aircraft are expected to be introduced into service in 1998 and then transitioned to similar components on advanced Navy aircraft.

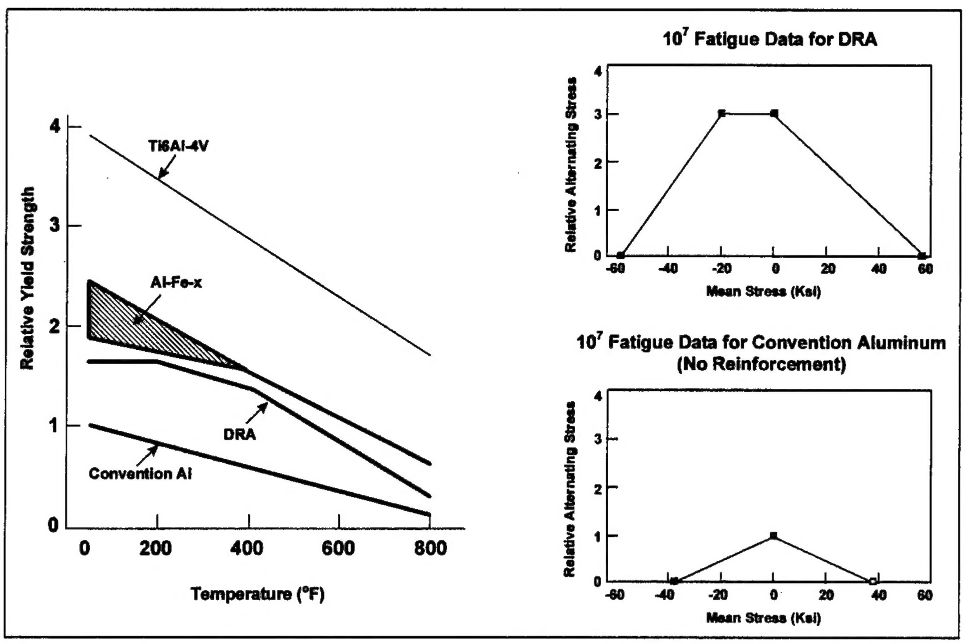


Figure 2
STRENGTH AND FATIGUE PROPERTIES OF DRA

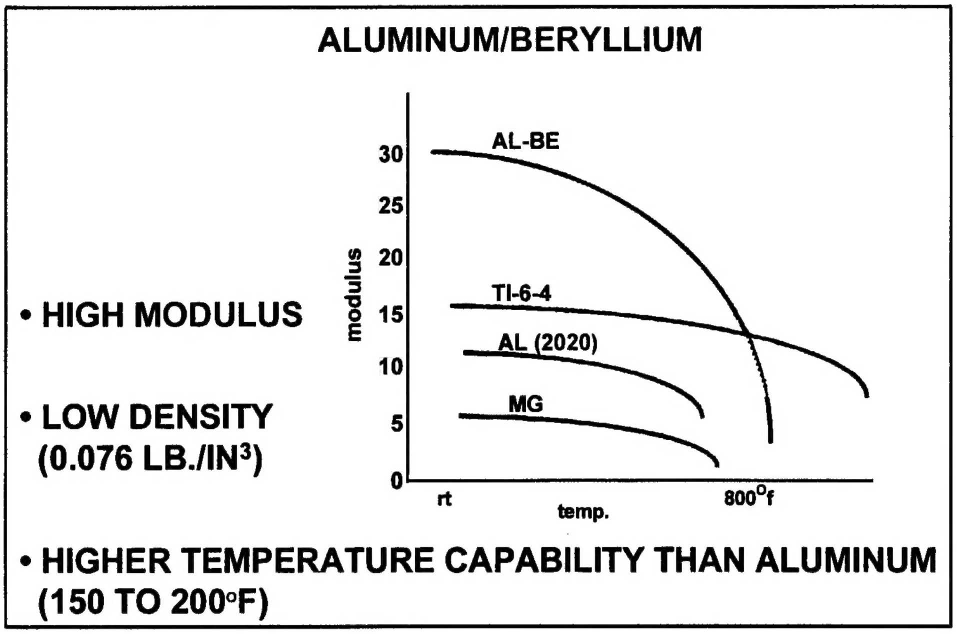


Figure 3
AlBe ADVANTAGES

ENGINES

Of all the Navy systems that use particulate processed materials, aircraft engines probably have the highest percentage of usage and certainly rely on these products more than any other systems. Figure 4 shows some of the important applications of particulate material technology.

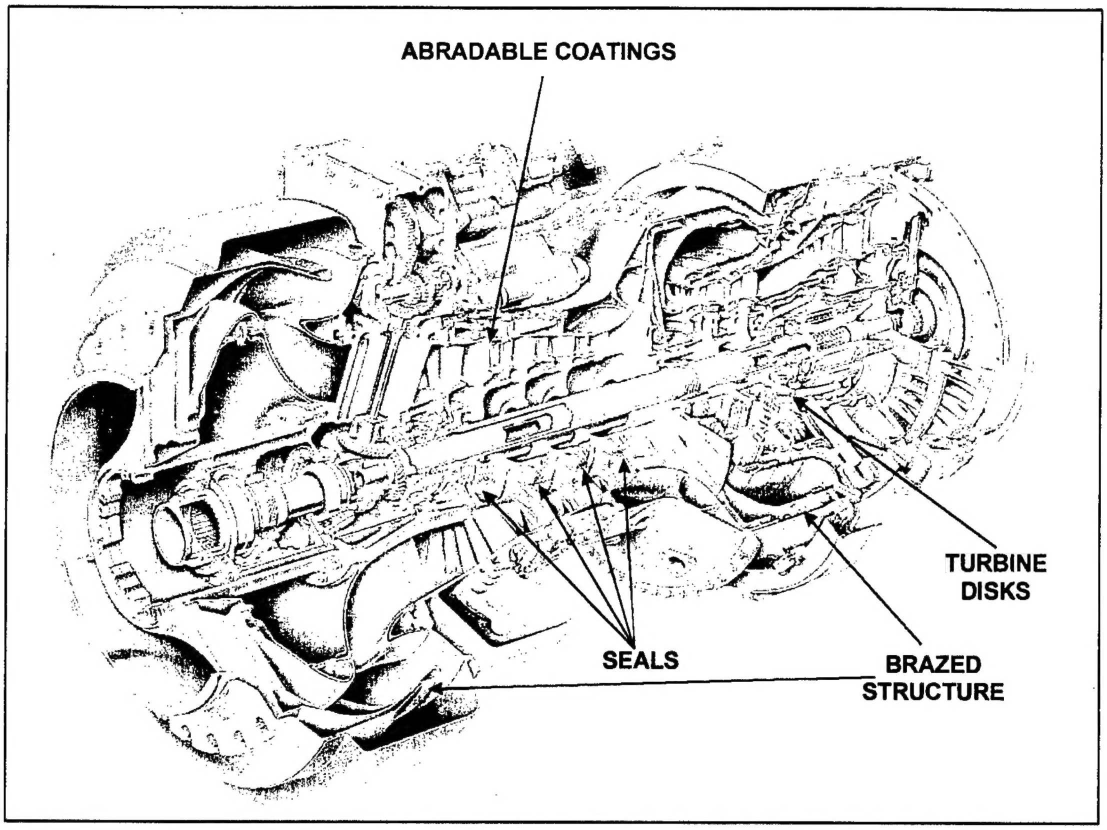


Figure 4
PARTICULATE MATERIAL USAGE IN AIRCRAFT ENGINES

Turbine disks are the most critical applications of power metallurgy products in current aircraft engines. The required properties of strength, low-cycle fatigue (LCF) resistance, and crack growth resistance at temperatures to 677°C (1,250°F) can only be obtained from highly alloyed nickel-base alloys. The alloys are difficult to cast due to the high alloy content and alloy segregation, and difficult to work due to high hot strength and low ductility in ingot form. Powder metallurgy processing eliminates both problems, while giving the additional benefits of a very fine grain size (strength and LCF resistance) and positive control of maximum defect size. While as hot isostatic pressing (HIP) products have been successfully used as disks, current applications are either HIP plus isoforged or extruded plus isoforged. The isoforging process breaks up so-called reactive defects that result from organic powder contaminates so that defects in the part are usually ceramic particles from the melting and pouring processes, with their size controlled by the powder mesh size.

After the disks, the most important powder application in engines is the use of sprayed powder abradable seal material (usually nickel aluminide and/or nickel graphite) to control the clearances between compressor blade tips and the compressor case. Poor performance of these seals can reduce engine performance by 5% or more.

The most immediate application of enhanced powder materials in engines is from clean powder programs being conducted by engine manufacturers. These programs focus on eliminating the ceramic particles that generally control the initiation of LCF failures in nickel alloy powder disks. The approach is through the use of ceramicless melting and pouring practices. When available, at competitive costs, these cleaner materials will be immediately incorporated into existing engines. Concurrent with the clean powder effort, there are programs to improve the percentage of usable material that the powder making process produces. The final step in the powder improvement process is to go to direct consolidation through a combined powder production/powder spraying operation.

One of the largest volume uses of particulate materials is in the production of oxidation/corrosion resistant coatings for turbine airfoils. These are generally forms of nickel aluminide that are produced by heating the part in powder consisting of aluminum, aluminum alloy, and a halide actuator. Since each part is coated at initial production and one or more times during service, the volume of powder used is quite large.

There are, of course, a large number of more mundane powder material applications in engines, which include abrasive materials on one side of a rotating seal (usually knife edge seals). The powder material is normally a carbide in a nickel matrix, and it is applied by a hot spray process. There are also powders used in brazing and the repair of worn surfaces to restore fits and clearances.

The next related powder material change in engines will likely be a dual property nickel turbine disk. The blade attachment area (the hottest part) will have a different structure and will probably be of a different alloy then the bore area (the highest stressed part). Both areas will be made of even more highly alloyed nickel and, therefore, will be powder processed. Initially, the bore and blade attachments area will be joined by diffusion or forge bonding, but the most desirable method will be direct gradient spray forming.

Other powder-based materials that will be used in specific applications are AlBe and TiBe, where high modulus is needed, and DRA alloys to replace titanium at the lower end of the temperature range.

Cost will continue to be a major driver for materials and processes, and probably will lead to some usage of powder-processed titanium alloys. This will particularly be true in the case of expendable engines (e.g., missile and target engines).

SURFACE SHIPS

Currently, surface ships do not use any significant amount of particulate processed materials. Possible future usage includes lower cost piping and pipe fittings, waste water incinerators for pollution control, corrosion resistant dual alloy mainshafts, and titanium valves, pipes, and fittings for firefighting systems. Use in ship-based systems could include bimetallic gun barrels and tungsten penetrators for projectiles to replace the controversial depleted uranium parts.

Since many modern Navy ships are now powered by gas turbines, almost all of the particulate material usages discussed under aircraft engines are also used in ship engines.

SUBMARINES

The application of particulate processed materials to submarines typically mimics the surface ship applications. The difference between the two is primarily the degree of reliability needed. Failures that can be tolerated in surface ships can be fatal in submarines, specifically in areas such as design margin and inspectability requirements.

CURRENT RESEARCH PROGRAMS

AIRCRAFT

AIRFRAMES

The primary emphasis in Navy development programs for airframe applications has been on increasing the temperature capability and corrosion resistance of aluminum alloys. Particulate processing has been the method used to investigate compositions that are difficult to make using conventional techniques. AlBe alloys have a great deal of potential for usage at temperatures up to 316°C (600°F), particularly in stiffness critical applications. They are currently candidates for lightweight hydraulic actuator housings operating at 204°C (400°F). This program is a cooperative program between NAWCAD Patuxent River and ONR. Initial evaluation of an extruded 62Be-35A1-3Mg alloy has indicated that these alloys have an outstanding combination of room temperature strength and 204°C (400°F) fatigue properties. Since actuators are ubiquitous in aircraft systems, success in this program is expected to lead to numerous additional applications.

In the area of increased corrosion resistance, Modified 7XXX series aluminum alloys containing 0.2% by volume (0.6% by weight) elemental molybdenum have been developed using rapid solidification power metallurgy techniques for which a U.S. Patent has been granted. The elemental molybdenum has been shown to enhance the environmentally assisted cracking resistance of 7075 aluminum alloys. A modest improvement in corrosion fatigue and stress corrosion cracking resistance was observed during testing in acidified chloride containing environments. A nondisclosure agreement has been made with Alcoa to produce experimental alloys, verify preliminary results, and further test the newly produced alloy. It is intended to verify the preliminary results of the modified 7075 alloy utilizing the new 7093 alloy modified with elemental molybdenum. A limited corrosion fatigue and stress corrosion cracking testing program to assess these potential effects is proposed.

Work in the area of aluminum/polymer composites is in its earliest stages of development. This unique, patented concept can also be applied to other systems. One method of producing these materials, “Polymets”, is coextension of mixed powders. At high extrusion ratios, polymer powder particles are converted into in situ fibers. These composites have improved damping and specific strength compared to the matrix alloy.

Of course, breakthroughs in areas such as direct HIP or injection molded titanium powder would find immediate application to airframe and engine components if the cost was competitive with conventional processing methods. Powder injection molding (PIM) has the potential for greatly reducing the cost of titanium and nickel-base alloy parts through near net shape forming as shown in figure 5.

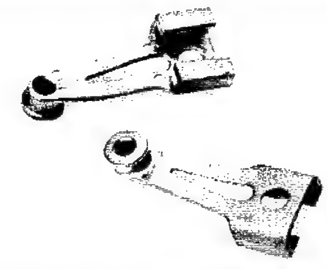
PROBLEM: JET ENGINES CONTAIN MANY SMALL COMPLICATED SHAPE COMPONENTS. COMPONENTS MADE FROM WROUGHT OR CAST MATERIALS USUALLY REQUIRE MULTIPLE SECONDARY FINISHING OPERATIONS WHICH INCREASE THE COMPONENT COST. **SOLUTION:** POWDER INJECTION MOLDING IS A COST EFFECTIVE PROCESS FOR MANUFACTURING METAL COMPONENTS THAT ELIMINATES SECONDARY OPERATIONS BY COMBINING THE NET SHAPE AND MASS PRODUCTION FEATURES OF PLASTIC INJECTION MOLDING AND THE EFFICIENT MATERIAL UTILIZATION OF POWDER METALLURGY.	 Actuator Arms for Variable Vane Assembly for the V-22 Helicopter Turbine Engine
APPROACH: FABRICATE AND ENGINE TEST A VANE ACTUATOR ARM FOR THE V-22 OSPREY T406-AD-400 ENGINE AND A FLANGED BUSHING FOR THE A4 SKYHAWK AND A6 INTRUDER J52-P-409 ENGINE. **APPLICATIONS:** COST SAVINGS FOR PIM TURBINE ENGINE COMPONENTS: - VANE ACTUATOR ARM (T406 ENGINE) - \$3K/ENGINE (\$1.8M/YEAR) - FLANGED BUSHING - \$277/ENGINE - SUPPORT SADDLE - \$3.4K/ENGINE (\$677/YEAR). PIM ALSO OFFERS DESIGN FLEXIBILITY THAT AFFORDS ADDITIONAL COST SAVINGS POTENTIAL.	**PERFORMING ORGANIZATION:** NATIONAL CENTER FOR METAL WORKING TECHNOLOGY (CONCURRENT TECHNOLOGIES CORPORATION) **SPONSOR:** NAVY MANTECH

Figure 5
PIM OF TURBINE ENGINE PARTS

ENGINES

The two major drivers for engine material development are cost and improved temperature capability with no reduction in design properties or weight. Decrease in component weight due to lower density is a bonus, but not a major objective. There is a lot of lip service given to weight, but essentially, cost wins every time.

There are potential applications for AlBe in advanced engines that essentially mirror the airframe applications for actuators. For engines, the working fluid is fuel rather than hydraulic fluid, but the temperatures are similar. The basic material development is directly transferable from the airframe program.

Dispersion reinforced aluminum is another material not directly developed for engines, but has properties that can be beneficial to engine applications, because it has the potential for replacing organic matrix composites (OMC's) in fan cases and fan stators at a lower cost. It also has

better erosion resistance and foreign object (debris sucked into the engine) damage resistance than OMC's. The engine-related development is primarily directed toward manufacturing technology to make stators by extrusion and cases by ring rolling or HIP.

With respect to materials applicable only to engines, nickel-based particulate materials are the most widely studied. The most basic work in this area involves direct spray forming of component shapes that are then HIPed, forged, or ring-rolled. The major advantage is, of course, reduced cost due to a very low "buy-to-fly" ratio and reduced machining costs. Another program supporting the direct spray technology and also conventional powder technology are the so-called clean powder programs. The intent of these programs is to eliminate any ceramic inclusions that could cause premature LCF failures in critical components. While this is important to conventional processing, it is critical to direct spraying. In conventional processing, the powder is sieved prior to consolidation and thus the maximum size of the defect is limited. This is difficult to do with direct spray.

While direct spray is under development, a great deal of interest lies in improving the material usage rate in conventional processes by either controlling the range of particulate sizes produced or allowing a wider range of particulate sizes in the final preform.

Particulate material produced oxidation/corrosion resistant coatings are being evaluated in a NAWCAD Patuxent River study aimed at reducing the large number of coatings used by various engine manufacturers down to a single "generic" coating. As shown in figure 6, this coating could then be used at Navy rework shops to recoat a wide variety of airfoils from different manufacturers. The reduction in equipment requirements and process control/monitoring will decrease both production and capital costs.

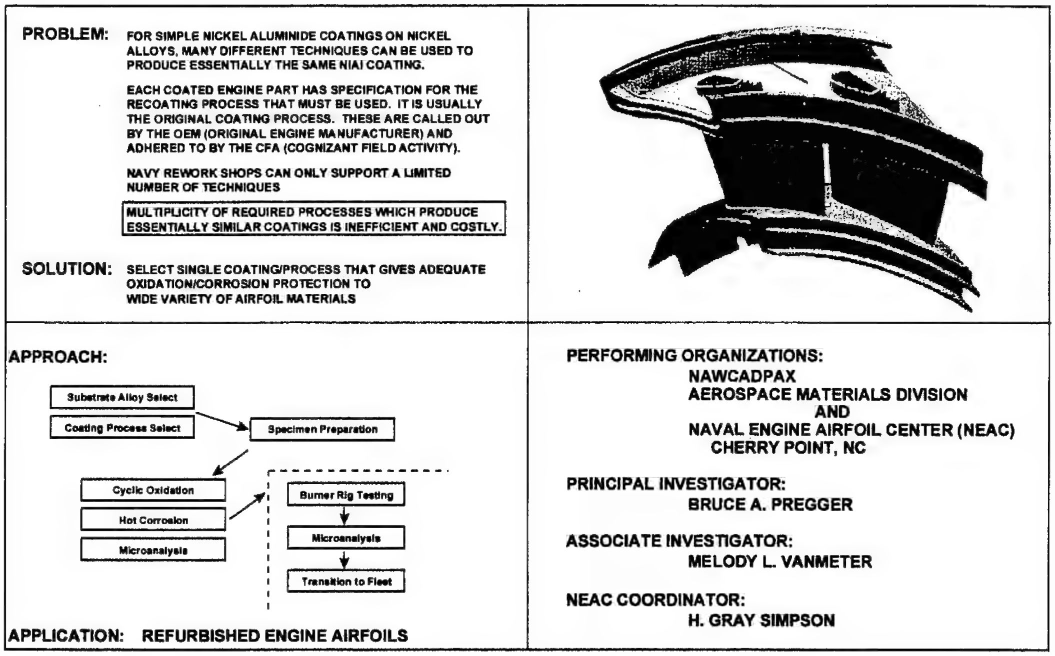


Figure 6
ALUMINIDE COATINGS FOR NAVY AIRCRAFT TURBINE APPLICATIONS

SHIP AND SUBMARINE

METAL SPRAY FORMING TECHNOLOGY (NSWCCD) (FIGURE 7)

The goal of this project was to develop and transition to industry new and improved metal spray forming processing methods to enable near net shape manufacture of military hardware at substantially lower acquisition costs with shorter production cycles and improved properties (e.g., strength and corrosion resistance). In addition, feasibility will be established for production of difficult to produce, highly reactive and clad metallic systems for machinery, propulsion, weapon system, and dual use applications.

Spray forming technology will be used in the manufacture of many future ship and submarine machinery, propulsion, and weapon system components. It can lead to substantial cost savings by reducing the number of manufacturing steps and results in 100% powder utilization. Conventional powder metallurgy produces a significant percentage of fine powder that is not usable. In addition, this process offers the opportunity to produce novel systems such as gradient compositions, thick claddings of hard or corrosion resistant materials, and in situ composites.

In the spray deposition process, a stream of molten metal is atomized by an inert gas, producing a spray of liquid droplets that are cooled by the gas and accelerated towards a substrate, where they consolidate to form a fully dense deposit. The process improves on ingot metallurgy in that a rapidly solidified, grain-refined microstructure with limited segregation is produced. Alternative net shape processing via powder metallurgy has not proven fully satisfactory because

The major limitation of current spray deposition technology is that it has relied almost entirely on a trial and error approach for process control. With significant industry and Navy investment, the process has matured and proven very attractive. A significant reduction in the cost of Alloy 625 submarine seawater piping was demonstrated by the application of spray forming technology.

Current materials for use in Navy/DoD machinery and propulsion system applications include many complex and expensive marine alloys. As Navy budgets are being dramatically reduced, there is a need to reduce the acquisition, maintenance, and logistic costs of military hardware. Also, alternate materials and processing methods are needed to be able to fabricate difficult-to-produce alloys and to provide materials with greater performance and durability at significantly reduced cost. Furthermore, as the number of weapon systems being produced is dramatically reduced, there is a need to be able to produce low-cost prototypes, reduce inventories, and compress manufacturing cycle times (time to market).

PART-ON-CALL MANUFACTURING

The objective of this program was to develop a low-capital, flexible spray forming manufacturing system for rapid production of prototype, limited production components and replacement parts for a wide variety of military and commercial applications through intelligent processing technology. Part-on-call (PoC) manufacturing via spray forming, as shown in figure 7, will dramatically reduce acquisition and logistic costs (inventory and unit costs) and provide the capability to rapidly produce prototypes or limited production items on demand.

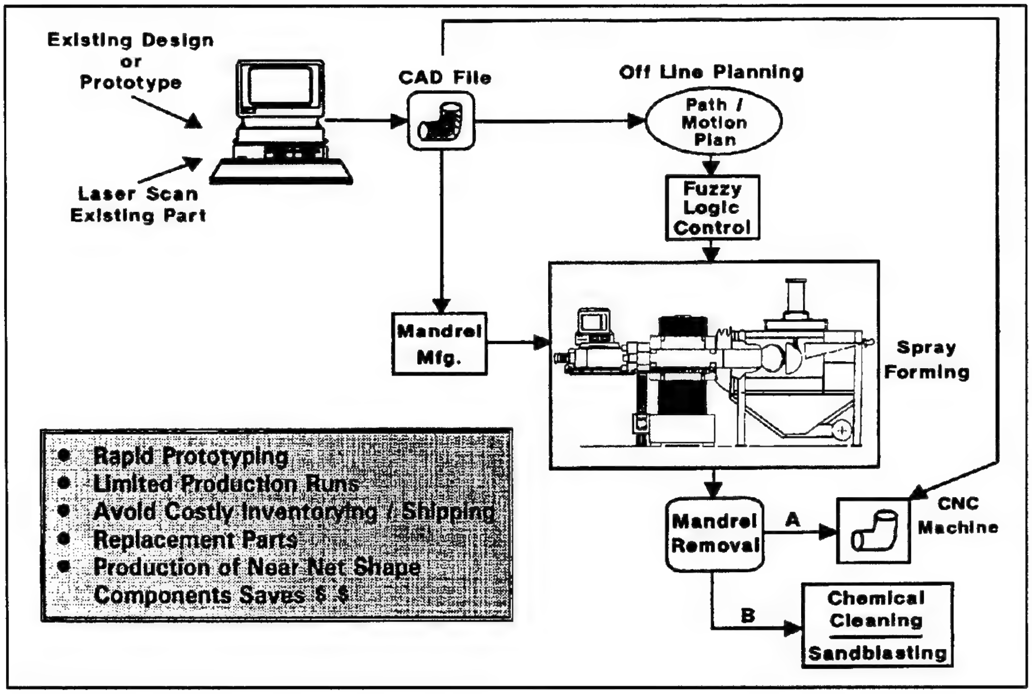


Figure 7
NEW INITIATIVE PoC MANUFACTURING

The PoC program couples the knowledge gained from modeling research and Intelligent Processing Spray Forming programs with state-of-the-art rapid prototyping/agile manufacturing concepts. The goal of this PoC program is to develop a manufacturing cycle that produces spray formed finished parts given only a CAD representation of the finished part and the desired alloy system. Furthermore, the program will combine and integrate a number of predictive tools, sensors, and process models with a fuzzy logic control system. The long-term benefit for the Navy will be a "PoC" production capability at shipyards and/or repair and manufacturing facilities.

The manufacturing cycle for the PoC program includes generating the following: the preform geometry from the CAD file, a Spray Process Plan, and a Manipulator Motion Plan based on the desired alloy; substrate design and configuration; and a Shape Model to simulate the geometry of spray forming part and secondary processing information. Once these actions are accomplished, the substrate can be manufactured and the part can be spray formed. The removal of the mandrel and any final NC machining yields a completed part.

For the initial demonstration of the PoC Spray Forming process, the part geometry was limited to tubular products with varying inner and outer diameter over 10 different segments. Multidiameter tubular products were chosen to complement a ManTech Spray Forming plant, which has the capability of producing 10 segmented, tubular products 8 to 32 in. in diameter, up to 20 ft long, and greater than 4 tons in weight.

TITANIUM SPRAY FORMING

The objective of this program was to demonstrate the feasibility of spray forming high quality (uncontaminated) near net shape reactive metal (titanium) products at a substantially reduced cost. A unique melting, dispensing, inert atmosphere controlled spray forming capability will yield quality near net shape titanium alloy preforms at a cost savings between 30-50%, compared to conventional processing methods. In addition, spray forming provides the opportunity to produce uniform, fine grained titanium alloy preforms for subsequent fabrication/working operations. Potential applications include advanced piping systems for ships and submarines, propulsion machinery (hot section items), and functional components. Development of this technology will also provide a basis for spray forming other reactive metal systems and/or difficult to produce alloys.

The target titanium spray forming demonstration component is a valve body used in titanium firemain systems. NSWCCD will spray form grain refined thixotropic titanium alloys that will be subsequently semi-solid formed by Concurrent Technology Corporation. Application of spray forming processes to fabricate other DoD titanium alloy components is being planned.

Titanium offers strength/weight and corrosion resistance advantages over many current high performance naval alloys, but because of its extreme reactivity when molten (or even at elevated temperatures), titanium must be protected from the atmosphere in order to avoid severe contamination by oxygen and nitrogen. To ensure quality, stringent precautions must be taken when melting, processing, and handling titanium and its alloys, thus increasing production time and costs. Therefore, to spray form titanium alloys, cold-hearth melting techniques must be coupled with a bottom pour nonreactive nozzle to supply the atomizer with a clean, molten stream of titanium alloy.

The technological challenge to successful titanium spray deposition is to supply a constant metal flow rate with an adequate controlled superheat in an inert environment without contamination by the nozzle material or the atmosphere. From a metallurgical perspective, minimizing the argon porosity and grain growth within the titanium preforms will be the technical challenge.

CLAD/LAYERED MATERIALS

The goal of this program was to develop processing methods to spray form bimetallic and/or graded tubular products. Clad or layered systems will have pervasive applications and cost savings for military and commercial platform systems. Alloy systems to be sprayed include nickel-base superalloys, stainless steels, and high-speed tool steels. The capability to rapidly produce low-cost components with an enhanced metallurgically bonded interface between a steel substrate and the value-added spray formed coating was demonstrated. This technology will provide the Navy with the capability to produce reduced cost Inconel clad steel shaft sleeves (rather than the current shrunk-fit sleeves) with improved metallurgical integrity and longevity. As a result, maintenance costs associated with shaft removal, inspection, and replacement would be eliminated.

Cladding technology can also be applied to seawater piping for naval applications as well as bimetallic gun barrels and other corrosion resistant and tribological applications. Spray forming offers a rapid means to make cost effective, long life bimetallic gun barrels. Specific applications include the 25mm Bushmaster (rapid fire) for protection of ships against missiles and projectiles and an extended range Navy 5-in. gun.

The manufacturing approach for Clad/Layered Materials will be to spray relatively thick coatings (10-40mm) onto a preheated substrate, followed by either machining or hot working to make the final bimetallic bar, plate, or tube. Metallurgical cladding or fusing alloys with different properties have a number of advantages, such as low cost and unique material performance characteristics. For many applications, a surface coating of an expensive alloy on a low cost substrate (such as steel) can replace a 100% through section of an expensive alloy. Unlike spray forming, most existing coating processes are slow (1-20 kg/hr), expensive, and generally restricted to thin layers (<1mm). Spray forming can affordably apply 10-40mm thick layers at very high production rates (5,000 kg/hr) with an improved metallurgical bond.

HIGH CHROMIUM ALLOYS FOR SHIPBOARD WASTE INCINERATORS

The Navy currently uses shipboard incinerators for disposal of blackwater. These incinerators utilize Alloy 690 (Ni-30%, Cr-10%, Fe), but can only operate at temperatures between 593°C (1,100°F) and 704°C (1,300°F). Higher temperatures 980°C (1,800°F) are required for a truly "multifunctional" shipboard incinerator. Increasing the Cr content of alloys is known to increase operational temperatures in many corrosive high temperature environments. However, alloys containing more than 30% Cr are extremely difficult to produce by hot working because of a brittle alpha chromium phase. Ni-Cr alloys will be developed containing Cr in the range of 30-60% for high temperature waste incinerators. Based on previous research by the International Nickel Company, zirconium alloying additions will be explored to improve room temperature ductility, and niobium and carbon additions will be explored to improve high temperature strength. The master alloys will be prepared by vacuum casting and spray formed. The spray formed preforms will be characterized microstructurally and evaluated for strength, ductility, hot workability, and hot corrosion resistance.

FUTURE DIRECTIONS

NEW ALLOYS/ALLOY SYSTEMS

The major emphasis on new alloys will continue to focus on the aluminum and nickel systems.

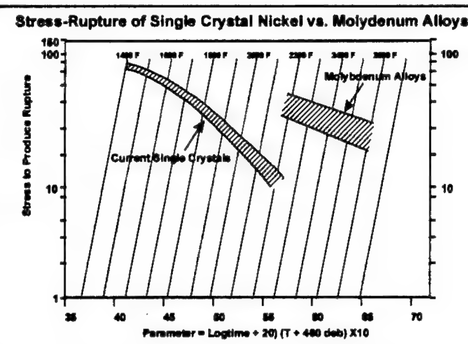
The aluminum systems can have a significant impact on aircraft weight and cost by replacing titanium components if we can get a moderate increase in temperature capability. The downside of this substitution is that titanium is essentially immune to corrosion problems. Weight and cost savings must be weighed against the potential corrosion problems.

The nickel-base systems are near their absolute use temperature, but there is nothing so far good enough to replace them. The potential returns are small, but important, and work will continue until another system comes along.

There is one program to evaluate refractory alloys that develop protective oxides. Particulate processing is used to produce the molybdenum base material. Figure 8 shows the potential benefits available from this system compared to current materials.

PROBLEM: CURRENT NICKEL BASE ALLOY TURBINE BLADES ARE USABLE TO LESS THAN 1,100°C BULK TEMPERATURE WHICH LIMITS ENGINE PERFORMANCE

SOLUTION: INVESTIGATE REFRACTORY METAL SYSTEMS CAPABLE OF OPERATING AT 1300 - 1400°C



APPROACH: EVALUATE AND OPTIMIZE A CLASS OF MOLYBDENUM ALLOYS THAT DEVELOPS A PROTECTIVE OXIDE. USING PARTICULATE PROCESSING TO PRODUCE BASE MATERIAL

APPLICATIONS: 1350°C TURBINE AIRFOILS FOR ADVANCED ENGINES

PERFORMING ORGANIZATION:
PRATT & WHITNEY

SPONSORING ORGANIZATION:
NAWCAD PAX
AEROSPACE MATERIALS DIVISION

CONTRACT MONITOR:
DR. G. LONDON

Figure 8
ADVANCED CONCEPTS ENGINE MATERIALS MOLYDENUM ALLOYS

POWDER PRODUCTION

The Naval Research Laboratory has a program to develop very fine metallic alloy powder by melt processing using energetic fluids as shown in figure 9. Metallic alloys in very fine powder form are made by crystallizing these fluids at a temperature well below their equilibrium melting temperatures. The approach involves having two energetic fluids (the melt spray and the rapidly spinning oil quenchant) impact each other in a counter-rotating mode to obtain a maximum transfer of mechanical energy. This process works because high degrees of undercooling are achieved through suppression of bulk nucleation and increased rate of cooling.

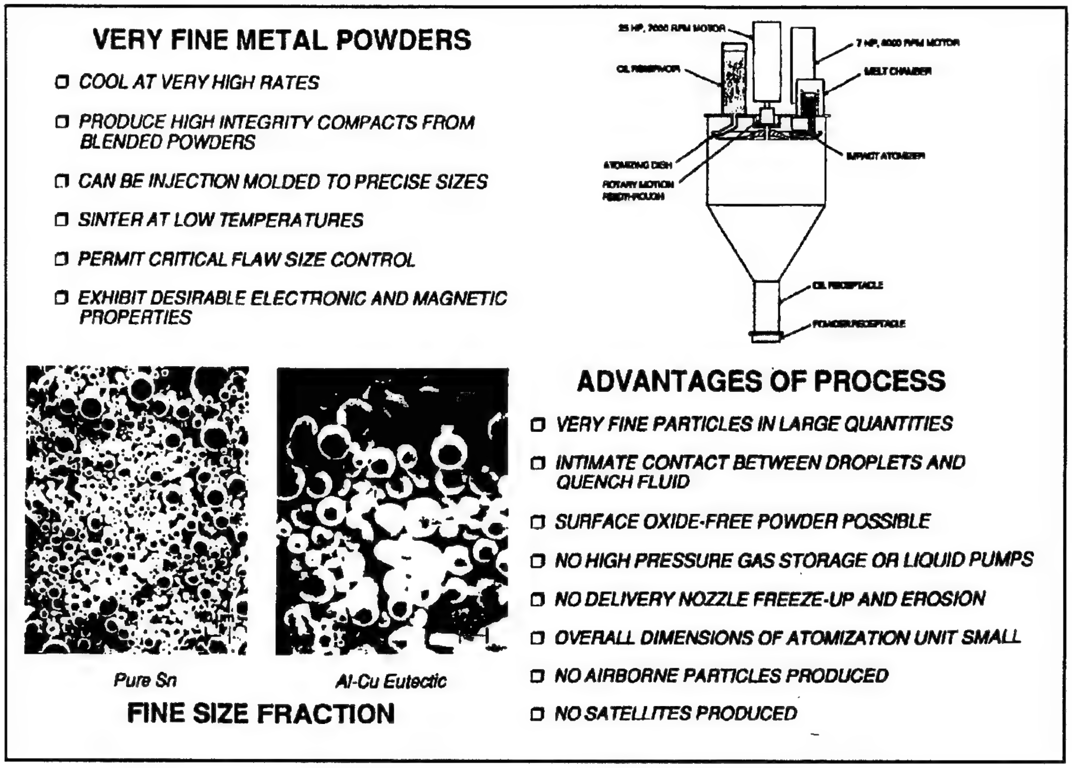


Figure 9
RAPIDLY SPINNING DISH ATOMIZATION

Work to date has resulted in building a novel, rapidly spinning dish atomizer, and a patent is pending. Future work will optimize the processing parameters to obtain efficient atomization of very fine aluminum alloy powders as well as investigating other atomizing fluids besides oil.

ONR has a program entitled "Enhanced Affordability Through Use of Nanoscale Coatings." In this program, nanoscale coating technology will be made available to vendors and ship yards in order to extend the service life of parts. High Velocity Oxy-Fuel thermal spray of nanoscale alloys will be developed as a replacement for weld overlay coatings, and nanoscale thermal barrier coatings will be developed for turbine blades to increase fuel efficiency and service life.

The objective of the program was to develop a capability to produce and deposit nanoscale ceramics, metal alloys, and cemented carbides (cermets) on various substrates to provide wear, erosion, corrosion, and/or thermal barrier protection. The specific types of parts addressed by this work are rotating parts subjected to wear, valve stems and valve seats subjected to erosion and corrosion, thermal barriers coatings for turbine blades for both shipboard and aircraft engines, and replacement coatings for weld overlay coatings. These parts will be placed in service for rigorous performance evaluation.

POWDER PROCESSING

One of the more interesting areas of powder processing involves the use of an exothermic reaction between elemental powders and metal carbides during HIP to form a near net shape intermetallic matrix composite as shown in figure 10. This process eliminates the need to make powder from intermetallics and carbides, and avoids the problems associated with HIPing hard, high melting point materials. The exothermic reaction aids in consolidation while the metal carbides produce a fine dispersion of highly stable reinforcing particles. The size of the carbides formed by the reaction are also small and more effective than those in a mechanical mixture.

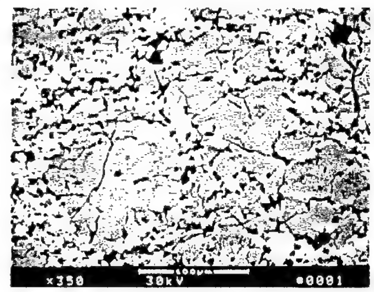
PROBLEM: DISCONTINUOUS INTERMETALLIC MATRIX COMPOSITE COMPONENTS MAY BE DIFFICULT TO CONSOLIDATE DUE TO LOW DIFUSIVITIVITY ACROSS PARTICLE BOUNDARIES, LACK OF PARTICLE DISTORTION, ETC. SOLUTION: REACT ELEMENTAL POWDERS DURING HIP PROCESSING TO FORM INSITU NEAR NET SHAPE INTERMETALLIC MATRIX COMPOSITES	
APPROACH: ESTABLISH NEEDED POWDER CHARACTERISTICS; SIZE, MORPHOLOGY, STOICHIOMETRY ESTABLISH THERMAL PROCESSING REQUIREMENTS; TEMPERATURE, PRESSURE TIME, RATES EMPLOY NAWC HIP SENSOR FOR REAL TIME DATA COLLECTION REACTIVE HIP ELEMENTAL POWDER/METAL CARBIDE MIXTURE TO PRODUCE A FINE DISPERSION OF HIGHLY STABLE REINFORCING PARTICLES INITIAL SYSTEM; TIAl/Nbc	PERFORMING ORGANIZATION: NAWCADPAX AEROSPACE MATERIALS DIVISION PRINCIPAL INVESTIGATOR: VEENA V. AGARWALA

Figure 10
REACTIVE PHASE, HOT ISOSTATIC PRESSING (RHIP) OF INTERMETALLIC MATRIX COMPOSITES

The Navy's program with the Concurrent Technology Center seeks to reduce cost and improve performance of weapons systems components by developing a verified comprehensive PM consolidation modeling system. Specifically, 2D and 3D constitutive models to simulate processing of metal powders will be developed to carry out testing procedures to calibrate the models. The model verification techniques include quantitative image analysis and data acquisition system on the powder compaction press to verify the model predictions. This comprehensive powder compaction modeling system will allow designers to determine the processing parameters and the part dimensions.

The goal of this program was to reduce design process cycle time for Navy and DoD PM parts by 50% by enabling the prediction of the required dimensions of the die and the as-pressed part. Emphasis on this work will involve samarium-cobalt magnets for aircraft/missile guidance systems for target drones and ceramic-oxide superconductor wire used in applications in Navy ship propulsion systems.

ONR is carrying out a program that involves developing lower cost processing methodology for HIP. The specific program is developing a canless HIP method by using Selective Laser Sintering (SLS). The method involves taking powder of either a titanium alloy or a steel and, by using SLS to melt the outside layers of powders, a high-density solid thin outside layer is put around the loose powders. This outside layer, or skin, serves as the so-called can for encapsulation of the powders, which are then HIPed to the desired component. By making use of this canless HIP process, the lead time for the process is decreased by about 60%, the part fabrication cost is reduced by about 40 to 50%, and the capability to make more complex parts is significantly enhanced because there is no need to produce the can and then to remove the can after HIPing. The canless HIP process will have a great impact on reducing the cost of producing high value Navy components.

POWDER APPLICATIONS

Waubik, Inc., is engaged in an SBIR-funded (Contract #N62269-94-C-1159, D.K. Dewald - Principal Investigator) project to develop sprayed powder protective coatings for TiAl- and Ti-alloy materials. These materials, specifically TiAl, have been selected for rotating gas path components in demonstrator aircraft engine designs. However, the best TiAl alloys only exhibit long-term oxidation resistance up to 700°C (1,300°F) despite higher temperature capabilities in terms of strength and creep resistance. Protective coatings are expected to allow higher service temperatures and prolonged lifetimes for these components. Waubik, Inc.'s, coatings are based on a cubic phase derivative of Al_3Ti, which contains approximately 10% Cr and has excellent oxidation resistance at temperatures up to 1,200°C (2,200°F). A major technological accomplishment of the program at Waubik has been the commercialization of cubic trialuminide alloy thermal spray powder, which is processed by gas atomization and available from Praxair Specialty Powders, Indianapolis, Indiana. Coatings have been processed by Low-Pressure Plasma Spray or, in most recent developments, by the lower cost Air Plasma Spray process. Early coatings demonstrated their protective capabilities, chemical compatibility, and excellent adhesion in 500 hr/cycle oxidation tests. A composite coating was formed by blending trialuminide alloy and Al_2O_3 powders, and a gradient structured coating was formed by varying the ratio of substrate TiAl alloy and cubic trialuminide powders fed to the plasma spray gun. As shown in the micrographs of as-deposited coatings and those subjected to a 200 hr/cycle oxidation test at 815°C (1,500°F), no micro/craze cracks formed during either processing or testing.

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CONCLUSIONS

The U.S. Navy recognizes the unique contribution particulate materials have for helping meet both performance and cost goals for current and advanced weapons systems. We are using particulate processing to investigate alloy systems that are impracticable to make by other methods, but which offer the advantages in either temperature capability or density critical to maintaining weapons superiority. We are also using this methodology to reduce acquisition and maintenance costs of weapon systems through the application of processes, such as direct spray forming and powder injection modeling. Finally, we are developing new processing methods such as Reactive Phase HIPing to further broaden the use of particulate materials.

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